

Single Spin Asymmetries in Semi-Inclusive Electroproduction: Access to Transversity

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Abstract. We discuss the quark transversity distribution function and a possible way to access it through the measurement of single spin azimuthal asymmetry in semi-inclusive single pion electroproduction on a transversely polarized target.

At leading order in $1/Q$, the cross section for a hard scattering process is given by the convolution of a hard part and a soft part. The former describes the scattering among elementary constituents and can be calculated perturbatively in the framework of QCD. The latter accounts for the processes in which either partons are produced from the initial hadrons (parton distribution functions) or final hadrons are produced from partons (parton fragmentation functions) which result from the hard elementary scattering.

For every quark flavor, besides the well-known parton distribution $f_1(x)$ and the longitudinal spin distribution $g_1(x)$, there is a third twist-two distribution function, the transversity distribution function $h_1(x)$ which was first discussed by Ralston and Soper [1] in double transverse polarized Drell-Yan scattering. The transversity distribution $h_1(x)$ measures the probability to find a transversely polarized quark in a transversely polarized nucleon. It is equally important for the description of the spin structure of nucleons as the more familiar function $g_1(x)$; their information being complementary. In the non-relativistic limit, where boosts and rotations commute, $h_1(x) = g_1(x)$; then difference between these two functions may turn out to be a measure for the relativistic effects within nucleons. On the other hand, there is no gluon analog on $h_1(x)$. This may have interesting consequences for ratios of transverse to longitudinal asymmetries in polarized hard scattering processes (see e.g. Ref. [2]).

The transversity distribution $h_1(x)$ remains still unmeasured. The reason is that

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it is a chiral odd function, and consequently it is suppressed in inclusive deep inelastic scattering (DIS) [3]. Since electroweak and strong interactions conserve chirality, $h_1(x)$ cannot occur alone, but has to be accompanied by a second chiral odd quantity.

In principle, transversity distributions can be extracted from cross section asymmetries in polarized processes involving a transversely polarized nucleon. In the case of hadron-hadron scattering these asymmetries can be expressed through a flavor sum involving a product of two chiral-odd transversity distributions. This is one of the main goals of the spin program at RHIC [4]. An evaluation of the corresponding asymmetry was carried out [5] by assuming the saturation of Soffer's inequality [6] for the transversity distribution: the maximum possible asymmetry at RHIC energies was estimated to be about 2%. At smaller energies ($\sqrt{s} \simeq 40$ GeV), e.g. for a possible fixed-target hadron-hadron spin experiment at the proposed HERA- \bar{N} facility [7] the asymmetry is expected to be higher (about 4%).

In the case of *semi-inclusive* deep inelastic lepton scattering² (SIDIS) off transversely polarized nucleons there exist several methods to access transversity distributions. One of them, the twist-3 pion production [8], uses longitudinally polarized leptons and measures a double spin asymmetry. The other methods do not require a polarized beam, and rely on the *polarimetry* of the scattered transversely polarized quark. They consist on:

- the measurement of the transverse polarization of Λ 's in the current fragmentation region [9,10],
- the observation of a correlation between the transverse spin vector of the target nucleon and the normal to the two-meson plane [11,12],
- the observation of the ‘‘Collins effect’’ in quark fragmentation through the measurement of pion single target-spin asymmetries [13–15].

In the following we will mainly focus on the last method.

To access the transversity in SIDIS off transversely polarized nucleons, one can measure the azimuthal angular dependences in the production of spin-0 or (on average) unpolarized hadrons. This production is described by the intrinsic transverse momentum dependent fragmentation function $H_1^\perp(z)$ which is also chiral odd and, moreover, T-odd, i.e., non-vanishing only due to final state interactions. Collins [13] was the first to propose such a spin dependent fragmentation function. It can be obtained, for example, in two-hadron production in e^+e^- annihilation [16]. In the cross section of SIDIS off transversely polarized nucleons it shows up as a $\sin(\phi_h + \phi_S)$ dependence, where ϕ_h is the azimuthal angle of the outgoing hadron (with non-zero transverse momentum P_{hT}) around the virtual-photon direction, and ϕ_S is the azimuthal angle of the target spin vector, both in relation to the lepton scattering plane.

²⁾ The relevant kinematics is: $Q^2 = -q^2$ where $q = k_1 - k_2$, k_1 (k_2) being the 4-momentum of the incoming (outgoing) charged lepton is the 4-momentum of the virtual photon. P (P_h) is the momentum of the target (final hadron), $x = q^2/2(Pq)$, $y = (Pq)/(Pk_1)$, $z = (PP_h)/(Pq)$

The $\sin(\phi_h + \phi_S)$ moment in the SIDIS cross-section can be related to the parton distribution and fragmentation functions involved in the parton level description of the underlying process [14,15]. This moment is defined as the appropriately weighted integral over P_{hT} (the transverse momentum of the observed hadron) of the cross section asymmetry:

$$\langle \frac{|P_{hT}|}{M_h} \sin(\phi_h + \phi_S) \rangle_{UT} \equiv \frac{\int d^2 P_{hT} \frac{|P_{hT}|}{M_h} \sin(\phi_h + \phi_S) (d\sigma^\uparrow - d\sigma^\downarrow)}{\frac{1}{2} \int d^2 P_{hT} (d\sigma^\uparrow + d\sigma^\downarrow)}, \quad (1)$$

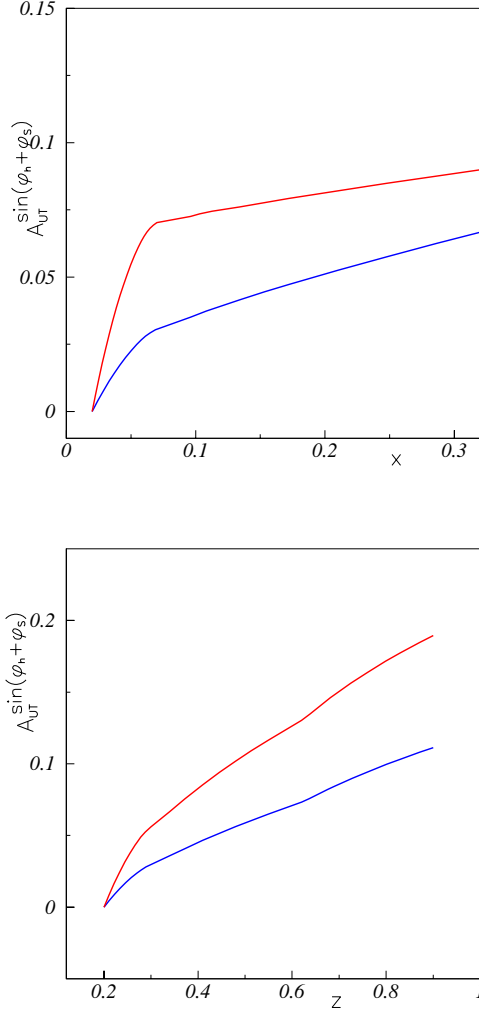


FIGURE 1. The single target-spin asymmetry $A_{UT}^{\sin(\phi_h + \phi_S)}$ for π^+ production as a function of x and z , evaluated using $M_C = 2m_\pi$ and $\eta = 0.8$ in Eq.(3). The two curves correspond to $h_1 = g_1$ (lower curve) and $h_1 = (f_1 + g_1)/2$ (upper curve).

where \uparrow (\downarrow) denotes the up (down) transverse polarization of the target in the virtual-photon frame, M (M_h) is the mass of the target (final hadron), and the subscripts U and T indicate unpolarized beam and transversely polarized target, respectively.

This asymmetry is given by [13–15]:

$$\langle \frac{|P_{hT}|}{M_h} \sin(\phi_h + \phi_S) \rangle_{UT} = 4S_T \frac{(1-y) h_1(x) z H_1^{\perp(1)}(z)}{(1 + (1+y)^2) f_1(x) D_1(z)}. \quad (2)$$

This weighted single target-spin asymmetry is related to the unweighted one through the following relation:

$$A_{UT}^{\sin(\phi_h + \phi_S)} \approx \frac{M_h}{\langle P_{hT} \rangle} \langle \frac{P_{hT}}{M_h} \sin(\phi_h + \phi_S) \rangle_{UT}. \quad (3)$$

Note that in the case of a longitudinally polarized target this asymmetry gives contribution to the $\sin\phi_h$ asymmetry [17], which was recently observed in semi-inclusive deep inelastic lepton scattering off a longitudinally polarized proton target at HERMES [18]. Describing this data by an approach where the transverse quark spin distribution in the longitudinally polarized nucleon is vanishing [20], only about 25% are contributed to $\sin\phi_h$ by the ‘kinematic’ term that is proportional to the transverse component of the nucleon spin vector with respect to the virtual-photon momentum.

For the numerical evaluation of the unweighted asymmetry $A_{UT}^{\sin(\phi_h + \phi_S)}$ the non-relativistic approximation $h_1(x) = g_1(x)$ is used as a lower limit and $h_1(x) = (f_1(x) + g_1(x))/2$ as an upper limit [6]. For the sake of simplicity, Q^2 -independent parameterizations were chosen for the distribution functions $f_1(x)$ and $g_1(x)$ [22].

To obtain the T-odd fragmentation function $H_1^{\perp(1)}(z)$, the Collins ansatz [13] for the analyzing power of transversely polarized quark fragmentation was adopted:

$$A_C(z, k_T) \equiv \frac{|k_T|}{M_h} \frac{H_1^{\perp}(z, k_T^2)}{D_1(z, k_T^2)} = \eta \frac{M_C |k_T|}{M_C^2 + k_T^2}, \quad (4)$$

where η is taken as a constant, although, in principle it could be z -dependent, and M_C is a typical hadronic mass whose value ranges from $2m_\pi$ to M_p .

In our calculations we use $M_C = 2m_\pi$ and $\eta = 0.8$ as in Ref. [21], where a good agreement was found with the single spin asymmetries of the distribution in the azimuthal angle ϕ_h for semi-inclusive π^+ production on a *longitudinally* polarized hydrogen target observed at HERMES [18,19].

For the distribution of the final parton intrinsic transverse momentum, k_T , in the unpolarized fragmentation function $D_1(z, k_T^2)$, a Gaussian parameterization was used [23] with $\langle z^2 k_T^2 \rangle = b^2$ (in the numerical calculations $b = 0.36$ GeV was taken [24]). For $D_1^{\pi^+}(z)$, the parameterization from Ref. [25] was adopted.

In Fig. 1, the asymmetry $A_{UT}^{\sin(\phi_h + \phi_S)}$ of Eq.(3) for π^+ production on a transversely polarized proton target is presented as a function of x and z . The curves have been

calculated by integrating over the HERMES kinematic range taking $\langle P_{hT} \rangle = 0.365$ GeV as input. The latter value is obtained in this kinematic region assuming a Gaussian parameterization of the distribution and fragmentation functions with $\langle p_T^2 \rangle = (0.44)^2$ GeV² [24].

From Fig. 1 one sees that the single transverse-target-spin asymmetry is quite large. In the HERMES kinematics ($\langle x \rangle \approx 0.1, \langle z \rangle \approx 0.4$) it amounts to $(4 \div 7)\%$. The HERMES experiment using a transversely polarized proton target will be able to extract $h_1(x)$ in a simple way, e.g. as suggested in Ref. [26]. First results on transverse quark spin distribution can be expected from combined results of HERMES and COMPASS within 3-5 years from now, while a complete high precision mapping of their Q^2 - and x -dependence requires next-generation facilities, such as TESLA-N [27], ELFE [28], eRHIC, EPIC, with high statistics measurements.

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